

# TITLE OF THE INVENTION

SEMICONDUCTOR CHARACTERISTIC EVALUATION APPARATUS

## CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2002-181459, filed June 21, 2002, the entire contents of which are incorporated herein by reference.

## BACKGROUND OF THE INVENTION

### 10 1. Field of the Invention

The present invention relates to a semiconductor characteristic evaluation apparatus. More particularly, it relates to an element characteristic/circuit characteristic evaluation apparatus which evaluates a fluctuation of element characteristics or circuit characteristics in a semiconductor integrated circuit (hereinafter, referred to as an LSI (large scale integrated circuit)).

### 2. Description of the Related Art

20 In LSIs after a 0.1  $\mu\text{m}$  generation, a fluctuation of element parameters must be taken into consideration, because an influence of the fluctuation of the element parameters becomes obvious, as the LSIs are more miniaturized and set to a lower voltage. In order to  
25 incorporate such a fluctuation of the element parameters into a design of the LSIs, it is necessary to accurately evaluate a fluctuation of element

characteristics in an LSI chip, in a wafer surface,  
between wafers and between lots. Especially, the  
evaluation in the LSI chip is also important in order  
to accurately estimate a fluctuation of circuit  
5 characteristics of the entire LSI chip.

Conventionally, the characteristics of the  
elements have individually been measured for the  
fluctuation evaluation. For example, element  
evaluation patterns necessary for the measurement are  
10 all arranged on the chip to prepare an evaluation chip.  
Usually, the arrangement of the element evaluation  
patterns needs an area of about several hundred  $\mu\text{m}$   
square. Accordingly, one or several chips are  
prepared, and all the element evaluation patterns are  
15 mounted thereon in accordance with the number of items  
to be measured. Then, during the measurement, the  
evaluation chips are mechanically moved in sequence to  
probe the individual element evaluation patterns.

Such a conventional method has the following  
20 drawbacks.

(1) Because of a large area of each element  
evaluation pattern, manufacturing costs of the  
evaluation chip become high. Additionally, since the  
element evaluation patterns are mounted on the chip in  
25 a wide range, it is difficult to distinguish a cause of  
a fluctuation correlation between elements from  
another, i.e., element characteristics from a

difference in distances or positions on the chip.

(2) A layout of the evaluation chips is far apart from a normal LSI. That is, the evaluation chips are laid out where probe pads are bedded. Accordingly, the evaluation chips are manufactured under conditions different from original process tuning conditions. Therefore, there is a problem that an obtained result of measurement is not accurate reflection of a fluctuation of element characteristics in the real LSI.

(3) The measurement is accompanied by mechanical movement and mechanical contact by a probe. Accordingly, measuring time becomes considerable to increase evaluation costs. Additionally, since the mechanical contact is repeated by a number of times (several tens of thousands in some cases), errors easily occur due to a guarantee of stability and a fluctuation of contact resistance.

(4) The number of element evaluation patterns to be mounted on one evaluation chip is limited to several hundreds to several thousands. For the same element evaluation patterns, only several to several tens can be mounted on one evaluation chip. By such mounted numbers, it is impossible to carry out satisfactory statistical evaluation. Evaluation is carried out by measuring several tens of evaluation chips, but it is nothing more than average evaluation for a number of evaluation chips. Consequently, it is impossible to

evaluate a difference among the evaluation chips, e.g., dependence on positions on the wafer.

(5) It is difficult to verify a correlation between obtained measurement data regarding the fluctuation of the element characteristics and the fluctuation of real circuit characteristics. A small volume of measurement data, a distance between the element evaluation patterns on the evaluation chip, and an inconsistent layout (e.g., a difference in pattern density or degree of miniaturization) are obstacles.

As against the aforementioned conventional method for mechanically moving the evaluation chips, there has been invented a method for electrically probing the element evaluation patterns, i.e., a method for electrically switching selection of patterns to be measured. In the case of this method, however, it has been considered that measurement accuracy necessary for evaluation cannot be secured due to an influence of an error caused by a leakage current of a changeover switch or a potential error caused by wiring resistance. Thus, the aforementioned method for mechanically moving the evaluation chips is still a mainstream evaluation apparatus.

#### BRIEF SUMMARY OF THE INVENTION

An object of the present invention is to provide a semiconductor characteristic evaluation apparatus which can accurately evaluate a fluctuation of element

characteristics and a fluctuation of circuit  
characteristics by electrically switching a measurement  
circuit system without any mechanical movement of an  
evaluation chip, and secure sufficient measurement  
5 accuracy necessary for evaluation.

According to a first aspect of the present  
invention, there is provided a semiconductor  
characteristic evaluation apparatus comprising a  
plurality of measurement units arranged on a chip, on  
10 which a plurality of measured patterns of components  
configuring a semiconductor integrated circuit and  
varying in kind from component to component are  
mounted; a measurement bus group arranged above the  
plurality of measurement units and connected to the  
15 plurality of measured patterns to configure a  
measurement circuit system in accordance with measured  
items of the components; a plurality of measurement  
pads, on the chip, which are arranged in a region other  
than an arrangement region of the plurality of  
20 measurement units and to which a measuring device is  
connected; a plurality of selection switches which  
select, in accordance with the measured items of the  
components, a measurement bus group configuring the  
measurement circuit system in accordance with the  
25 measured items and which connect the group to the  
plurality of measurement pads; and a control circuit  
which electrically controls switching of the plurality

of selection switches in accordance with the measured items of the components.

According to the foregoing constitution, the components constituting the semiconductor integrated circuit mounted on the plurality of measurement units arranged on the chip are connected to the plurality of measured patterns varied in kind from component to component, whereby the connection between the measurement bus group constituting the measurement circuit system and the measurement pad in accordance with the measured items of the components is electrically controlled by the selection switch. The measurement bus group and the selection switch enable an optimal structure of the measurement circuit system and optimal application of a bias voltage. As a result, it is possible to prevent an influence of an error caused by leakage current of the changeover switch or a potential error caused by wiring resistance.

Additional objects and advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and obtained by means of the instrumentalities and combinations particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the invention.

FIG. 1 is a plan view showing a constitutional example of an element characteristic/circuit characteristic evaluation apparatus according to an embodiment of the present invention.

FIG. 2 is a view showing an example of a basic measurement unit in the element characteristic/circuit characteristic evaluation apparatus of FIG. 1.

FIG. 3 is a view showing a constitutional example of a resistance measurement circuit in the element characteristic/circuit characteristic evaluation apparatus of FIG. 1.

FIG. 4A is a view showing a constitutional example of a capacity measurement circuit in the element characteristic/circuit characteristic evaluation apparatus of FIG. 1.

FIG. 4B is a view showing an example of an operation waveform of the capacity measurement circuit.

FIG. 5 is a view showing a constitutional example of an n-type MOS (metal oxide semiconductor) transistor measurement circuit in the element

characteristic/circuit characteristic evaluation  
apparatus of FIG. 1.

FIG. 6 is a view showing a constitutional example  
of a p-type MOS transistor measurement circuit in the  
5 element characteristic/circuit characteristic  
evaluation apparatus of FIG. 1.

FIG. 7 is a view showing a constitutional example  
of a ring oscillator measurement circuit in the element  
characteristic/circuit characteristic evaluation  
10 apparatus of FIG. 1.

FIG. 8 is a view showing an example of a mesh  
measurement bus which constitutes a measurement bus in  
the element characteristic/circuit characteristic  
evaluation apparatus of FIG. 1.

15 FIG. 9 is a view showing an example of a straight  
measurement bus which constitutes the measurement bus  
in the element characteristic/circuit characteristic  
evaluation apparatus of FIG. 1.

FIG. 10 is a view showing a constitutional example  
20 of a driving clock straight measurement bus of the  
capacity measurement circuit in the element  
characteristic/circuit characteristic evaluation  
apparatus of FIG. 1.

FIG. 11 is a view showing a straight measurement  
25 bus for the ring oscillator measurement circuit in the  
element characteristic/circuit characteristic  
evaluation apparatus of FIG. 1.



FIG. 12 is a view showing another example of an n-type MOS transistor measurement circuit.

FIG. 13 is a view showing another example of a p-type MOS transistor measurement circuit.

5        FIG. 14 is a view showing another constitutional example of a mesh measurement bus.

FIG. 15 is a view showing another constitutional example (measurement bus net) of a capacity measurement circuit.

10       FIG. 16 is a view showing yet another constitutional example (measurement bus net) of a capacity measurement circuit.

FIG. 17 is a view showing yet another constitutional example (measurement bus net) of a ring  
15       oscillator measurement circuit.

FIGS. 18A to 18C are plan views showing constitutional examples of unit arrays in the element characteristic/circuit characteristic evaluation apparatus of FIG. 1.

20       FIGS. 19A to 19C are sectional views showing constitutional examples of capacity measurement wirings in the element characteristic/circuit characteristic evaluation apparatus of FIG. 1.

#### DETAILED DESCRIPTION OF THE INVENTION

25       Embodiments of the present invention will hereinafter be described in reference to the drawings.

FIG. 1 shows a configuration example of an element

characteristic/circuit characteristic evaluation  
apparatus in accordance with one embodiment of the  
present invention. In FIG. 1, a unit array 10 is  
provided on an evaluation chip 1. The unit array 10  
5 comprises 196 basic measurement units (MAU =  
Measurement Array Unit) 11 as measurement units, which  
are arranged in a lattice-like form by  $14 \times 14$ , for  
example. On the unit array 10, measurement buses (bus  
group for measurement) 20 and a plurality of X address  
10 selection signal lines 31 and a plurality of Y address  
selection signal lines 32 are arranged. The  
measurement buses 20, the plurality of X address  
selection signal lines 31 and the plurality of Y  
address selection signal lines 32 are each connected to  
15 the corresponding basic measurement units 11.

An X address decoder (control circuit) 33 is  
disposed at an outer peripheral portion of the chip 1,  
for example, on a left side of the unit array 10. A Y  
address decoder (control circuit) 34 is disposed on a  
20 lower side of the unit array 10. These decoders 33, 34  
output an X address selection signal and a Y address  
selection signal based on a control signal supplied  
from the external of the evaluation chip 1, respec-  
tively. More specifically, the X address selection  
25 signal output from the decoder 33 is supplied to the  
corresponding basic measurement units 11, for example,  
via the X address selection signal lines 31. Further,

the Y address selection signal output from the decoder 34 is supplied to the corresponding basic measurement units 11, for example, via the Y address selection signal lines 32.

5           A plurality of measurement terminal pads (measurement pads) 40 is arrayed on a lower side of the Y address decoder 34. The X address decoder 33, Y address decoder 34, and measurement bus 20 are each connected to the measurement terminal pads 40.

10          Further, a measurement equipment (not shown) is connected to each measurement terminal pad 40, thus inputting the control signals and outputting measurement data from each of the basic measurement units 11.

15           FIG. 2 shows one configuration example of the basic measurement unit 11. The basic measurement unit 11 is divided into, for example, five areas 11a, 11b, 11c, 11d and 11e. Each of the areas 11a, 11b, 11c, 11d and 11e is equipped with several tens of measured  
20          patterns, which are different in kinds such as configuration, size and shape, of components (semiconductor elements or integrated circuits and delay circuits including semiconductor elements) that compose an LSI. More specifically, the area 11a is,  
25          for example, a resistance measurement pattern area, and this area is equipped with a resistive element which is one of the components, or several tens of patterns of

resistance measurement circuits (measured patterns)  
including the resistive element. The area 11b is, for  
example, a capacity measurement pattern area, and this  
area is equipped with a capacity element which is one  
5 of the components, or several tens of patterns of  
capacity measurement circuits (measured patterns)  
including capacity element. The area 11c is, for  
example, an n-type MOS transistor measurement pattern  
area, and this area is equipped with an n-type MOS  
10 transistor which is one of the components, or several  
tens of patterns of n-type MOS transistor measurement  
circuits (measured patterns) including the n-type MOS  
transistor. The area 11d is, for example, a p-type MOS  
transistor measurement pattern area, and this area is  
15 equipped with a p-type MOS transistor which is one of  
the components, or several tens of patterns of p-type  
MOS transistor measurement circuits (measured patterns)  
including the p-type MOS transistor. The area 11e is,  
for example, a ring oscillator measurement pattern  
20 area, and this area is equipped with several tens of  
patterns of ring oscillator measurement circuits  
(measured patterns) in which the delay circuits, which  
are one of the components, have different delay times.

Here, the basic measurement unit 11 is configured  
25 with a size of about several hundred  $\mu\text{m}$  square, for  
example. Therefore, each of the areas 11a, 11b, 11c,  
11d and 11e can be equipped with several tens or more

(several tens of kinds to several hundreds of kinds) of measured patterns therein.

FIG. 3 shows a configuration example of the resistance measurement circuit installed in the resistance measurement pattern area. This resistance measurement circuit is configured with four n-type MOS transistors 11a-1, 11a-2, 11a-3, 11a-4, and a measured element 11a-5 comprising one resistive element, for example. Gates of the n-type MOS transistors 11a-1, 11a-2, 11a-3, 11a-4 are each connected to a control terminal 11a-6. Drains of the n-type MOS transistors 11a-1, 11a-2, 11a-3, 11a-4 are connected to a measurement terminal If+, a measurement terminal Vs+, a measurement terminal Vs-, and a measurement terminal If-, respectively. Sources of the n-type MOS transistors 11a-1, 11a-2, 11a-3, 11a-4 are connected in common. The measured element 11a-5 is connected between the sources of the n-type MOS transistors 11a-2, 11a-3. In addition, a parasitic resistance 11a-7 is connected between the sources of the n-type MOS transistors 11a-1, 11a-2, and a parasitic resistance 11a-8 is connected between the sources of the n-type MOS transistors 11a-3, 11a-4.

In this resistance measurement circuit, a measurement current If is applied across the measurement terminals If+, If-, thereby measuring a potential difference between the measurement terminals

Vs+, Vs-. If the potential difference is Vs, a resistance value R of the measured element 11a-5 is expressed by the following equation (1).

$$R = V_s / I_f \quad \dots (1)$$

5           FIGS. 4A and 4B show one example of the capacity measurement circuit installed in the capacity measurement pattern area. Here, a capacity measurement circuit is taken as an example, which is configured by a CBCM (Charge-based Capacitance Measurement) method  
10       (e.g., refer to "James C. Chen, Dennis Sylvester, Chenming Hu, Hitoshi Aoki, Sam Nakagawa, Soo-Young Oh, "An On-Chip, Interconnect Capacitance Characterization Method with Sub-Femto-Fared Resolution," Proc. IEEE 1997 Int. Conference on Microelectronic Test  
15       Structures, vol. 10, pp. 77-80, March 1997.").

          As shown in FIG. 4A, for example, this capacity measurement circuit is configured with a p-type MOS transistor (M1) 11b-1 and an n-type MOS transistor (M2) 11b-2 that constitute a CMOS inverter, a measured  
20       element 11b-3 comprising a capacity element, a NAND circuits 11b-4, 11b-5, a NOR circuit 11b-6, and inverter circuits 11b-7, 11b-8, 11b-9, 11b-10 and 11b-11. A source of the p-type MOS transistor 11b-1 is connected to a power source for capacity measurement  
25       VDD(sense) terminal, and a gate (terminal A) thereof is connected to an output terminal of the NAND circuit 11b-4. A source of the n-type MOS transistor 11b-2 is

connected to a ground (GND(sense)) terminal, and a gate (terminal B) thereof is connected to an output terminal of the NOR circuit 11b<sub>-6</sub>. The measured element 11b<sub>-3</sub> is connected between a common drain (terminal C) of the  
5 p-type MOS transistor 11b<sub>-1</sub> and n-type MOS transistor 11b<sub>-2</sub>, and the ground. One input terminal of the NAND circuit 11b<sub>-5</sub> is connected to a control terminal 11b<sub>-12</sub>, and the other input terminal 11b<sub>-13</sub> is supplied with a drive clock. An output terminal of the NAND  
10 circuit 11b<sub>-5</sub> is connected to an input terminal of the inverter circuit 11b<sub>-7</sub>. An output terminal of the inverter circuit 11b<sub>-7</sub> is connected to one input terminal of the NAND circuit 11b<sub>-4</sub> and one input terminal of the NOR circuit 11b<sub>-6</sub>. Also, the output  
15 terminal of the inverter circuit 11b<sub>-7</sub> is connected to an input terminal of the inverter circuit 11b<sub>-8</sub>. An output terminal of the inverter circuit 11b<sub>-8</sub> is connected to an input terminal of the inverter circuit 11b<sub>-9</sub>. An output terminal of the inverter circuit  
20 11b<sub>-9</sub> is connected to an input terminal of the inverter circuit 11b<sub>-10</sub>. An output terminal of the inverter circuit 11b<sub>-10</sub> is connected to an input terminal of the inverter circuit 11b<sub>-11</sub>. An output terminal of the inverter circuit 11b<sub>-11</sub> is connected to the other input  
25 terminal of the NAND circuit 11b<sub>-4</sub> and the other input terminal of the NOR circuit 11b<sub>-6</sub>.

This capacity measurement circuit utilizes the

fact that current consumed by the CMOS inverter becomes the product of a drive voltage, frequency and load capacity. As FIG. 4B shows operating waveforms, for example, potentials (waveforms) of the terminal A and terminal B are adjusted so that the p-type MOS transistor 11b<sub>-1</sub> and n-type MOS transistor 11b<sub>-2</sub> should not be turned on simultaneously. The measured element 11b<sub>-3</sub> connected to the terminal C is driven by a potential difference V<sub>ddc</sub> between the power source for capacity measurement VDD(sense) and the ground (GND(sense)).

If a frequency of the drive clock is  $f_c$  and an average current value of the power source for capacity measurement VDD(sense) is  $I_{ddc}$ , a capacity value  $C_d$  of the measured element 11b<sub>-3</sub> can be expressed by the following equation (2).

$$C_d = I_{ddc} / (f_c \cdot V_{ddc}) \quad \dots (2)$$

FIG. 5 shows a configuration example of the n-type MOS transistor measurement circuit installed in the n-type MOS transistor measurement pattern area. In this n-type MOS transistor measurement circuit, for example, a gate of a measured element 11c<sub>-1</sub> comprising an n-type MOS transistor is connected to a measurement terminal n-Gate via a transfer gate (switch circuit) 11c<sub>-2</sub>. A drain of the measured element 11c<sub>-1</sub> is connected to a measurement terminal n-Drain, and a source thereof is connected to a



measurement terminal n-Source. A drain of an n-type MOS transistor 11c<sub>3</sub> is connected to the gate of the measured element 11c<sub>1</sub>. A source of the n-type MOS transistor 11c<sub>3</sub> is grounded, and a gate thereof is  
5 connected to a p-type MOS transistor side gate of the transfer gate 11c<sub>2</sub> and an output terminal of an inverter circuit 11c<sub>4</sub>. A control terminal 11c<sub>5</sub> and an n-type MOS transistor side gate of the transfer gate 11c<sub>2</sub> are connected to an input terminal of the  
10 inverter circuit 11c<sub>4</sub>.

In this n-type MOS transistor measurement circuit, a bias potential for characteristic measurement is applied across the measurement terminal n-Drain and measurement terminal n-Source. When the control  
15 terminal 11c<sub>5</sub> has a low potential, a gate potential of the measured element 11c<sub>1</sub> becomes a ground potential, and the n-type MOS transistor 11c<sub>3</sub> is turned off. When the control terminal 11c<sub>5</sub> has a high potential, a potential of the measurement terminal n-Gate is applied  
20 to the gate of the measured element 11c<sub>1</sub>. As a result, the n-type MOS transistor 11c<sub>3</sub> is turned on, and the characteristic of the measured element 11c<sub>1</sub> can be measured.

FIG. 6 shows a configuration example of the p-type  
25 MOS transistor measurement circuit installed in the p-type MOS transistor measurement pattern area. In this p-type MOS transistor measurement circuit, for

example, a gate of a measured element 11d<sub>1</sub> comprising a p-type MOS transistor is connected to a measurement terminal p-Gate via a transfer gate (switch circuit) 11d<sub>2</sub>. A drain of the measured element 11d<sub>1</sub> is  
5 connected to a measurement terminal p-Drain, and a source thereof is connected to a measurement terminal n-Source. Also, a drain of a p-type MOS transistor 11d<sub>3</sub> is connected to the gate of the measured element 11d<sub>1</sub>. A source of the p-type MOS transistor 11d<sub>3</sub> is  
10 connected to a power source VDD, and a gate thereof is connected to an n-type MOS transistor side gate of the transfer gate 11d<sub>2</sub> and a control terminal 11d<sub>4</sub>. An input terminal of an inverter circuit 11d<sub>5</sub> is connected to the control terminal 11d<sub>4</sub>. An output  
15 terminal of the inverter circuit 11d<sub>5</sub> is connected to a p-type MOS transistor side gate of the transfer gate 11d<sub>2</sub>.

In this p-type MOS transistor measurement circuit, a bias potential for characteristic measurement is  
20 applied across the measurement terminal p-Drain and measurement terminal p-Source. When the control terminal 11d<sub>4</sub> has a low potential, a gate potential of the measured element 11d<sub>1</sub> becomes high, and the p-type MOS transistor 11d<sub>3</sub> is turned off. When the control  
25 terminal 11d<sub>4</sub> has a high potential, a potential of the measurement terminal p-Gate is applied to the gate of the measured element 11d<sub>1</sub>. As a result, the p-type

MOS transistor 11d<sub>3</sub> is turned on, and the characteristic of the measured element 11d<sub>1</sub> can be measured.

FIG. 7 shows a configuration example of the ring oscillator measurement circuit installed in the ring oscillator measurement pattern area. This ring oscillator measurement circuit is configured, for example, with a measured circuit 11e<sub>1</sub> comprising a ring oscillator section, an inverter circuit 11e<sub>2</sub>, a dividing circuit 11e<sub>3</sub>, and an output buffer (tristate buffer) 11e<sub>4</sub>. The measured circuit 11e<sub>1</sub> has one NAND circuit 11e<sub>1a</sub> and six inverter circuits 11e<sub>1b</sub>, 11e<sub>1c</sub>, 11e<sub>1d</sub>, 11e<sub>1e</sub>, 11e<sub>1f</sub> and 11e<sub>1g</sub>. A control terminal 11e<sub>5</sub> and the output buffer 11e<sub>4</sub> are connected to one input terminal of the NAND circuit 11e<sub>1a</sub>. An output terminal of the NAND circuit 11e<sub>1a</sub> is connected to an input terminal of the inverter circuit 11e<sub>1b</sub>. An output terminal of the inverter circuit 11e<sub>1b</sub> is connected to an input terminal of the inverter circuit 11e<sub>1c</sub>. An output terminal of the inverter circuit 11e<sub>1c</sub> is connected to an input terminal of the inverter circuit 11e<sub>1d</sub>. An output terminal of the inverter circuit 11e<sub>1d</sub> is connected to an input terminal of the inverter circuit 11e<sub>1e</sub> and an input terminal of the inverter circuit 11e<sub>2</sub>. An output terminal of the inverter circuit 11e<sub>1e</sub> is connected to an input terminal of the inverter circuit

11e-1f. An output terminal of the inverter circuit 11e-1f is connected to an input terminal of the inverter circuit 11e-1g. An output terminal of the inverter circuit 11e-1g is connected to the other input  
5 terminal of the NAND circuit 11e-1a. An output terminal of the inverter circuit 11e-2 is connected to an input terminal of the output buffer 11e-4 via the dividing circuit 11e-3. An output terminal of the output buffer 11e-4 is connected to a measurement  
10 terminal F0.

In this ring oscillator measurement circuit, when the control terminal 11e-5 has a low potential, an output of the NAND circuit 11e-1a in a first step is fixed to a high potential. Accordingly, the measured  
15 circuit (ring oscillator section) 11e-1 is brought in an oscillation-stopped state. At this moment, the tristate buffer 11e-4 in an output step brings a divided output of the measurement terminal F0 into a high impedance state because the control terminal 11e-5  
20 has a low potential. If the control terminal 11e-5 has a high potential, the NAND circuit 11e-1a in the first step outputs an inverted logical value of the other input (the other input terminal). In this way, the measured circuit 11e-1 oscillates. After properly  
25 divided by the dividing circuit 11e-3, this oscillation output is output from the measurement terminal F0. That is, when the control terminal 11e-5 has a high

potential, the tristate buffer 11e<sub>4</sub> at the output becomes effective, and the oscillation output of the ring oscillator section (11e<sub>1</sub>) is divided and output from the measured terminal F0.

5           FIG. 8 to FIG. 11 show one example of the measurement bus 20. In the present embodiment, the measurement bus 20 is configured with a mesh measurement bus (second bus) 21 shown in FIG. 8, and straight measurement buses (first buses) 22, 23, and 24  
10           respectively shown in FIG. 9 to FIG. 11.

          The mesh measurement bus 21 has a mesh structure comprising a plurality of lateral wires (lateral buses) 21a and a plurality of vertical wires (vertical buses) 21b which is in a different layer from that of the  
15           lateral wires 21a, for example, as shown in FIG. 8. A space between the wires 21a and a space between the wires 21b almost correspond to a space between the arranged basic measurement units 11. At each  
20           intersection point, the wires 21a, 21b are interconnected by a via contact 21c. The wires 21a, 21b are connected to one of the measurement terminal pads 40 via a lateral wire 21d constituted in the same layer as that of the vertical wires 21b. With such a mesh structure, it is possible to form the mesh  
25           measurement bus 21 having low resistance in which all the buses can be fixed to the same potential.

          In addition, plural sets of mesh measurement buses

21 are arranged in an upper layer of the basic measurement units 11 mentioned above, correspondingly to the total number of basic measurement units 11, for example (details will be described later).

5           The straight measurement bus 22 has a stripe structure comprising a plurality of vertical wires (vertical buses) 22a which is in the same layer as that of the vertical wires 21b, for example, as shown in FIG. 9. More specifically, a predetermined number of  
10       wires 22a are each arranged in the spaces between the vertical wires 21b of the mesh measurement bus 21 (details will be described later). The wires 22a are connected to one of the measurement terminal pads 40 via a plurality of selection switches 22b comprising  
15       n-type MOS transistors and p-type MOS transistors, and a lateral wire 22c. Each of the selection switches 22b is controlled by a signal from the Y address selection signal lines 32, for example. That is, only parts of the plurality of selection switches 22b corresponding  
20       to measured items (resistance, capacity, transistor, delay circuit) in each basic measurement unit 11 are turned on, and the rest are turned off. Unnecessary measurement bus nets (measurement circuit systems) are shut off by turning on only the necessary parts of the  
25       selection switches 22b, thereby making it possible to prevent a leak current flow.

          The straight measurement bus (for capacity

measurement drive clock) 23 has a stripe structure comprising a plurality of vertical wires (vertical buses) 23a which is in the same layer as that of the vertical wires 21b, for example, as shown in FIG. 10.

5 More specifically, a predetermined number of wires 23a are each arranged in the spaces between the vertical wires 21b of the mesh measurement bus 21 (details will be described later). The wires 23a are connected to two of the measurement terminal pads 40 via a plurality  
10 of measurement bus selection gates (selection switches) 23b, a lateral wire 23c and a differential clock buffer 23d. Each of the measurement bus selection gates 23b is controlled by a signal from the Y address selection signal lines 32, for example. That is, a drive clock  
15 is supplied to only necessary parts of the vertical wires 23a by means of the plurality of measurement bus selection gates 23b. In this way, it is possible to prevent unnecessary current consumption and noise occurrence.

20 The straight measurement bus 24 is a measurement bus for measuring ring oscillators, and has a stripe structure comprising a plurality of vertical wires (vertical buses) 24a which is in the same layer as that of the vertical wires 21b, for example, as shown in  
25 FIG. 11. More specifically, a predetermined number of wires 24a are each arranged in the spaces between the vertical wires 21b of the mesh measurement bus 21

(details will be described later). The wires 24a are connected to two of the measurement terminal pads 40 via a plurality of measurement bus selection gates (selection switches) 24b, a lateral wire 24c and a differential output buffer 24d. Each of the measurement bus selection gates 24b is controlled by a signal from the Y address selection signal lines 32, for example. That is, only necessary parts of the vertical wires 24a are made effective by the plurality of measurement bus selection gates 24b. In this way, it is possible to prevent unnecessary current consumption and noise occurrence.

Here, connection relationships (measurement bus nets) of the resistance measurement circuit, capacity measurement circuit, n-type MOS transistor measurement circuit, p-type MOS transistor measurement circuit and ring oscillator measurement circuit with the measurement bus 20 will be described.

In the resistance measurement circuit (see FIG. 3), the measurement terminals  $I_{f+}$ ,  $I_{f-}$ ,  $V_{s+}$ ,  $V_{s-}$  are each connected to the vertical wires 22a of the straight measurement bus 22 shown in FIG. 9, thereby configuring a desired measurement bus net. In this case, n-type MOS transistors are used for the selection switches 22b. A logic (not shown) which takes the logical product of the X address selection signal lines 31 and Y address selection signal lines 32 is connected



to the control terminal 11a<sub>6</sub>. In addition, the measurement terminal If- can also be connected to the mesh measurement bus 21 shown in FIG. 8. In that case, the selection switch (transistor 11a<sub>4</sub>) linked to the measurement terminal If- may be omitted.

In the capacity measurement circuit (see FIG. 4A), the terminal of the power source for capacity measurement VDD(sense) is connected to the vertical wires 22a of the straight measurement bus 22 shown in FIG. 9 (in this case, p-type MOS transistors are used for the selection switches 22b). The input terminal 11b<sub>13</sub> of the NAND circuit 11b<sub>5</sub> is connected to the vertical wires 23a of the straight measurement bus 23 shown in FIG. 10. Further, the ground (GND(sense)) terminal is connected to one of the plural sets of mesh measurement buses (see FIG. 8) 21, thereby configuring a desired measurement bus net. Moreover, a logic (not shown) which takes the logical product of the X address selection signal lines 31 and Y address selection signal lines 32 is connected to the control terminal 11b<sub>12</sub>. In this way, the drive clock of the capacity measurement circuit is supplied from the vertical wires 23a of the straight measurement bus 23. As a result, the measurement current to which capacity-current conversion has been applied by the CBCM method is output via the vertical wires 22a of the straight measurement bus 22.

In the n-type MOS transistor measurement circuit (see FIG. 5), the measurement terminals n-Drain, n-Source, n-Gate are each connected to the plural sets of mesh measurement buses (see FIG. 8) 21, thereby  
5 configuring a desired measurement bus net. A logic (not shown) which takes the logical product of the X address selection signal lines 31 and Y address selection signal lines 32 is connected to the control terminal 11c-5. In this n-type MOS transistor  
10 measurement circuit, a potential drop during measurement can be restricted by using the mesh measurement buses 21, thereby enabling highly accurate measurement.

In the p-type MOS transistor measurement circuit  
15 (see FIG. 6), the measurement terminals p-Drain, p-Source, p-Gate are each connected to the plural sets of mesh measurement buses (see FIG. 8) 21, thereby configuring a desired measurement bus net. A logic (not shown) which takes the logical product of the X  
20 address selection signal lines 31 and Y address selection signal lines 32 is connected to the control terminal 11d-4. In this p-type MOS transistor measurement circuit, a potential drop during measurement can be restricted by using the mesh  
25 measurement buses 21, thereby enabling highly accurate measurement.

In the ring oscillator measurement circuit (see

FIG. 7), the measurement terminal F0 is connected to the vertical wires 24a of the straight measurement bus 24 shown in FIG. 11, thereby configuring a desired measurement bus net. A logic (not shown) which takes the logical product of the X address selection signal lines 31 and Y address selection signal lines 32 is connected to the control terminal 11e-5.

In the present embodiment, seven sets of mesh measurement buses 21, five vertical wires 22a, one vertical wire 23a and one the vertical wire 24a are allocated to one basic measurement unit 11, for example. That is, if the number of basic measurement units 11 is "196 ( $= 14 \times 14$ )", the measurement bus 20 is constituted by seven sets of mesh measurement buses 21, the straight measurement bus 22 having 70 ( $= 14 \times 5$ ) vertical wires 22a, the straight measurement bus 23 having 14 vertical wires 23a, and the straight measurement bus 24 having 14 vertical wires 24a.

In addition, the measurement bus 20 is designed to have the optimum configuration and optimum bias conditions in accordance with the characteristics of the measured elements 11a-5, 11b-3, 11c-1, 11d-1, and the characteristics of the measured circuit 11e-1. That is, by selecting the proper configuration of the measurement bus 20 and optimum bias conditions for each measurement circuit correspondingly to the characteristics of the circuit, it is possible to avoid error

factors that affect the measurement such as the leak current of the selection switches and potential drop caused by the parasitic resistance of the measurement bus 20.

5           Furthermore, regardless of the kind of measurement circuit, the X, Y address decoders 33, 34 on the evaluation chip 1, a power source (not shown) and the like are shared.

10           Still further, functions of the X, Y address decoders 33, 34 include, for example, mode setting of the measurement circuits and monitoring of internal operation in addition to addressing, which are not described in detail though.

15           In the element characteristic/circuit characteristic evaluation apparatus with such a configuration, measurement equipment is connected to the measurement terminal pads 40. Further, control signals, and power source and measurement biases corresponding to the measurement items and the like are  
20           input via the measurement terminal pads 40. Then, in accordance with the control signals, the measurement bus 20 is selectively connected to the measurement terminal pads 40, and one of the resistance measurement circuit, capacity measurement circuit, n-type MOS  
25           transistor measurement circuit, p-type MOS transistor measurement circuit or ring oscillator measurement circuit in the basic measurement unit 11 connected to

the measurement bus 20 is put under a controlled state. In this way, the connection of the measurement bus net, which corresponds to the measurement item, to the measurement terminal pads 40 is electrically switched, thereby outputting an output (measurement data) of the circuit put in the controlled state to the measurement equipment from the measurement terminal pads 40 via the measurement bus 20.

As described above, several hundreds of basic measurement units with a size of several hundred  $\mu\text{m}$  square are arranged on the same chip in a lattice-like form. The basic measurement units are equipped with several tens to several hundreds of variations of measurement circuits with different configurations and sizes of element resistance (parasitic resistance) that decides the delay time, capacity (parasitic capacity), transistors and the like, and equipped with several tens to several hundreds of measurement circuits that are differ in sample circuits capable of evaluating the delay time of the ring oscillator and the like. These measurement circuits are components (measured elements or measured circuits) of an LSI. In this case, the number of measurement circuits mounted on one basic measurement unit amounts to several hundred in total, while the number of measured patterns per chip amounts to several tens of thousands to several hundred thousands.

Furthermore, the measurement bus provided with the selection switches is suitably connected to each basic measurement unit, so as to constitute a measurement bus net between the measurement bus and the measurement circuit. The connection of this measurement bus net with the measurement terminal pads is electrically switched by controlling the selection switches on the basis of the control signal.

In this way, it is possible to obtain the measurement data on measured patterns of several tens of thousands to several hundred thousands per chip by electrically enabling the selection of the measured patterns without mechanically moving the evaluation chip. Especially, since all the measured patterns are put together in the basic measurement unit of several hundred  $\mu\text{m}$  square, it is possible to accurately evaluate the correlation of a fluctuation of characteristics among the measured patterns individually. Moreover, in this method, while the selection of the measured patterns is electrically switched, constitution of the measurement buses and bias application method can be optimized in accordance with the measurement items, thereby enabling required measurement accuracy to be ensured.

For example, when the size of one basic measurement unit is 250  $\mu\text{m}$  square, a chip of 3.5  $\mu\text{m}$  square can be broken into 196 ( $14^2$ ) for evaluation. In

this way, sufficient spatial resolution can be secured for a normal LSI chip size (several mm squares to ten mm square or so). Moreover, 196 samples can be obtained per chip, which enables accurate statistical evaluation.

More specifically, the use of the method in accordance with the present embodiment makes it possible to solve the following problems posed in the conventional method.

(1) Per chip, several tens of thousands to several hundred thousands measured patterns can be evaluated. As a result, an about double-digit improvement can be accomplished in the production cost of the chip in relation to an amount of data that can be collected.

(2) The measurement terminal pads can be arranged only in the vicinity of an outer periphery of the chip. That is, the measured elements and measurement circuits can be arranged with high density in the basic measurement unit. This provides a layout quite similar to that of the normal LSI, so that it is possible to collect measurement data reflecting a characteristic fluctuation of the elements in the actual LSI.

(3) The elements are individually measured by electrically switching the connection. In that case, one chip is mechanically moved to contact a certain measured element only one time. As a result, a common effect of the parasitic resistance is made on the

individual measured patterns, which makes it possible to accurately evaluate a characteristic fluctuation of the elements in the chip. Further, since the number of mechanical contacts is decreased, the entire measurement time is barely increased even if a measurement sequence is introduced to check contact resistance. As a result, it is possible to easily ensure stability in the contact resistance and accurately evaluate the characteristic fluctuation of the elements in the chips.

(4) The basic measurement units of several hundred  $\mu\text{m}$  square are arranged in a lattice-like form, thereby allowing several hundreds of measurement data on the same measured element to be obtained per chip. This enables highly accurate statistical evaluation with one chip, and also enables correlation between elements to be analyzed per chip.

(5) Since all the measured patterns are put together in the basic measurement unit of several hundred  $\mu\text{m}$  square, the layout is quite similar to that of the normal LSI, and it is possible to evaluate, with a high degree of reliability, not only the correlation of a characteristic fluctuation among the elements but also the correlation of a delay time fluctuation among circuits with the characteristic fluctuation.

Next, another embodiment in accordance with the present invention will be described.



FIG. 12 shows another configuration example of the n-type MOS transistor measurement circuit. In the n-type MOS transistor measurement circuit (see FIG. 5), all the measured elements  $11c_1$  in the area are  
5 connected to the mesh measurement bus 21. Therefore, an off-leak of the n-type MOS transistor has a significant influence on the measurement accuracy. In order to restrict the off-leak of the n-type MOS transistor, an off-bias potential GNDE is connected to  
10 a source of an n-type MOS transistor  $11c_3'$ , for example, as shown in FIG. 12. In this way, the off-bias potential GNDE is applied as a gate potential of the measured element  $11c_1$  when it is not selected. As a result, it is possible to reduce the leak current  
15 flowing across the measurement terminals n-Drain, n-Source, and improve the measurement accuracy.

FIG. 13 shows another configuration example of the p-type MOS transistor measurement circuit. In this p-type MOS transistor measurement circuit, an off-bias  
20 potential VDDE is connected to a source of a p-type MOS transistor  $11d_3'$ , for example. In this way, the off-bias potential VDDE is applied as a gate potential of the measured element  $11d_1$  when it is not selected. This reduces an off-leak of the p-type MOS transistor. As a result, it is possible to reduce the leak current  
25 flowing across the measurement terminals p-Drain, p-Source, and improve the measurement accuracy, as in

the n-type MOS transistor measurement circuit shown in FIG. 12.

FIG. 14 shows another configuration example of the mesh measurement bus shown in FIG. 8. A mesh measurement bus (second bus) 21A in this example is divided into four divisional buses (groups) 21B, for example. By being divided, this mesh measurement bus 21A can reduce the parasitic resistance and leak current (off-leak current from the measured element flowing into each of the divisional buses 21B). Especially, the mesh measurement bus 21A can be used to measure transistors, so that the measurement accuracy of on-current is improved.

FIG. 15 shows another configuration example of the capacity measurement circuit (measurement bus net). In this example, a selection switch (selection circuit) 11b-21 comprising a p-type MOS transistor is connected in common to the p-type MOS transistors 11b-1 of all the capacity measurement circuits (see FIG. 4A) in the capacity measurement pattern area 11b in each basic measurement unit 11. A gate of the selection switch 11b-21 is connected to a control terminal 11b-22. In each basic measurement unit 11, all the capacity measurement circuits are connected to the vertical wires 22a of the straight measurement bus 22 via the selection switch 11b-21, thereby configuring a measurement bus net for capacity measurement. In this

way, it is possible to shut off leak currents from more unnecessary circuits (off-leak of the transistors 11b<sub>-1</sub>) and improve the measurement accuracy.

FIG. 16 shows still another configuration example of the measurement bus net for capacity measurement. Normally, in a CMOS circuit, a power source potential is applied to a well of the p-type MOS transistor. In the measurement bus net shown in FIG. 15, the measurement terminal pads 40 to which a power source VDD(sense) EXT is applied can be regarded as a power source terminal. Therefore, the well is fixed by the potential of the measurement terminal pads 40. Consequently, the leak current to flow into the selection switches (well of the p-type MOS transistor) 22b then flows into the measurement terminal pads 40, which could cause measurement errors. To prevent this, in the measurement bus net in this example, the wells are connected to the sources in selection switches 22b', 11b-21', and the p-type MOS transistors 11b-1' of all the capacity measurement circuit, for example, as shown in FIG. 16. As a result, it is possible to shut off unnecessary leak current components flowing into the wells.

FIG. 17 shows another configuration example of the measurement bus net for ring oscillator measurement. In this example, all the ring oscillator measurement circuits (see FIG. 7) in the ring oscillator

measurement pattern area 11e in each basic measurement unit 11 are constituted to share the dividing circuit 11e-3. Further, in each basic measurement unit 11, all the ring oscillator measurement circuits are connected to the measurement bus 20 via a selection gate 11e-11, thereby configuring a measurement bus net for ring oscillator measurement. In addition, a control terminal 11e-12 is connected to the selection gate 11e-11.

FIGS. 18A to 18C show other configuration examples of the unit array. In addition, FIG. 18A shows a basic arrangement of the basic measurement units 11 in the unit array 10 shown in the embodiment described above, and here shows an example of a  $4 \times 4$  arrangement of the basic measurement units 11. FIG. 18B shows an example of a  $4 \times 4$  arrangement of the basic measurement units in which a common portion is provided for each  $4 \times 1$  ( $n$  alignments ( $n > 1$ )) alignment, and FIG. 18C shows an example of a  $4 \times 4$  arrangement of the basic measurement units in which a common portion is provided for  $4 \times 4$  ( $n$  alignments ( $n > 1$ )) alignments.

More specifically, when only a particular measurement pattern area needs a relatively large area, common portions 11A' are arranged which step over plural sets (here,  $n = 4$ ) of basic measurement units 11A to provide common parts in the area, for example, as shown in FIG. 18B. This makes it possible to hold

an excessive increase of the area in the case of a unit array 10A. In addition, the common portions 11A' may all be the same measurement pattern area, or can be different measurement pattern areas.

5           Furthermore, as shown in FIG. 18C, for example, it is also possible to arrange a common portion 11B' in the spaces among a plurality (here,  $n = 16$ ) of basic measurement units 11B. A unit array 10B with such a configuration is especially effective when it is  
10           necessary to arrange vertical long wires and lateral long wires in the measurement pattern area.

          FIGS. 19A to 19C show examples in which lowered-capacity wires, and lowered-capacity and lowered-resistance wires are used to improve capacity  
15           measurement accuracy. In addition, FIG. 19A shows a common wiring structure comprising five layers of laminated wires (first wire layer to fifth wire layer), FIG. 19B shows one example of a lowered-capacity wiring structure in which target wires have lowered capacity,  
20           and FIG. 19C shows one example of a lowered-capacity and lowered-resistance wiring structure in which target wires have lowered capacity and lowered resistance.

          Here, in the case of the capacity measurement circuit composed by the CBCM method (see FIG. 4A), a  
25           measurement current flowing through the measured element 11b<sub>-3</sub> changes in proportion to a frequency of the drive clock. The higher the measurement current

is, the less a leak current causes an error. That is,  
the higher the frequency of the drive clock is, the  
more the measurement accuracy is improved. However, if  
higher speed is enabled in the straight measurement bus  
5 23 for the drive clock shown in FIG. 10, noise produced  
on the chip 1 is increased.

Furthermore, as shown in FIG. 15, the parasitic  
capacity and parasitic resistance of the straight  
measurement bus 22 restricts response of the capacity  
10 measurement circuit. Therefore, the measurement bus  
net needs to have lowered-capacity and lowered-  
resistance in order to achieve accurate measurement at  
high frequency.

In the lowered-capacity wires shown in FIG. 19B,  
15 for example, among first, second, third wire layers  
22-1, 22-2, 22-3 constituted by small pitch wires, and  
fourth, fifth wire layers 22-4, 22-5 constituted by  
large pitch wires, a target wire 22x constituted by the  
third wire layer 22-3 has lowered capacity. Taking a  
20 copper (Cu) wiring process of a 0.13  $\mu\text{m}$  generation as  
an example, the parasitic capacity of the target wire  
22x is 0.1 pF/mm, which is about half of a parasitic  
capacity of the general third wire layer 22-3 of  
0.2 pF/mm. That is, by using the lowered-capacity  
25 wires having a wiring structure of this kind as the  
straight measurement bus for the drive clock in the  
capacity measurement circuit, the noise produced on the

chip 1 can be reduced by half, as compared with the case where the general wires (see FIG. 19A) are used.

In the lowered-capacity and lowered-resistance wires shown in FIG. 19C, for example, among the first, second, third wire layers 22<sub>-1</sub>, 22<sub>-2</sub>, 22<sub>-3</sub> constituted by the small pitch wires, and the fourth, fifth wire layers 22<sub>-4</sub>, 22<sub>-5</sub> constituted by the large pitch wires, a target wire 22y constituted by the fourth wire layer 22<sub>-4</sub> has lowered capacity and lowered resistance.

Taking the Cu wiring process of the 0.13  $\mu\text{m}$  generation as an example, the parasitic capacity of the target wire 22y is 0.12 pF/mm, which is about half of a parasitic capacity of the general fourth wire layer 22<sub>-4</sub> of 0.24 pF/mm. Further, a wiring resistance is 50  $\Omega/\text{mm}$ , which is about half of a wiring resistance of the general fourth wire layer 22<sub>-4</sub> of 100  $\Omega/\text{mm}$ .

That is, by using the lowered-capacity and lowered-resistance wires having a wiring structure of this kind as the straight measurement bus for the outputting measurement currents in the capacity measurement circuit, it is possible to reduce the noise on the chip 1 and secure high-speed response when the drive clock is speeded up. The response can be about four times as fast as that in the case where the general wires (see FIG. 19A) are used.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore,

the invention in its broader aspects is not limited to  
the specific details and representative embodiments  
shown and described herein. Accordingly, various  
modifications may be made without departing from the  
5 spirit or scope of the general invention concept as  
defined by the appended claims and their equivalents.